Social housing design: influences from triple bottom line (3BL) concept

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In recent years, there has been a significant supply of housing units through social housing projects (SHP) in Brazil, mostly fuelled by subsidy programs and federal government funding. Therefore, the efficient design and implementation of these projects is an important aspect with regard to optimal use of resources. Under the Triple Bottom Line (3BL) concept - people, planet, profit - it is crucial to understand the decisions taken at the building design stage, when one has the greatest influence on factors that can reduce costs, improve housing conditions and minimize environmental impacts. In this context, the objective of this research is to analyze the environmental impacts, the cost and habitability aspects of housing units in a SHP, based on the 3BL concept. To this purpose, the volumetry of buildings was analyzed and the economic index of compactness (EIC) of the H-shaped buildings used in the base-project was calculated. Then, the building design was modified and two simulations of projects were proposed, seeking to increase the EIC and improve habitability issues. The improved-EIC alternatives had its embodied energy (EE) quantified and compared with the base-project, covering the environmental aspect of 3BL. The benefits that these design changes had in the housing units, as well as the cost impacts of the project as a whole, were also analyzed, thus considering social and economic aspects as well. The results indicate a reduction of production costs of 10% in the proposed projects and improvements in many aspects of habitability, as natural lighting and cross ventilation. Furthermore, there was a reduction of 7.5% in EE, also in favor of the proposed projects with improved EIC. Converting the difference of EE in electric power, for example, the savings generated would be sufficient to supply all the energy needs of 20 housing units (one tower) for 4.5 years.

Keywords: social housing design, economic indices of compactness, habitability, embodied energy.

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1. Introduction

For the first time in history, the majority of the world population is living in cities. However, about a billion people live in informal settlements, as slums, and this number is projected to be about two billion people in 2030. Attracted to urban areas in search of jobs and greater social recognition, many urban migrants are suffering from insecurity, limited access to services such as sanitation and potable water and basic conditions of habitability (SMITH, 2007). Still according to the author, about 90% of the world population has little or no access to most basic goods and services, which demonstrates the urgent need to design and seek solutions for this significant proportion of inhabitants. This scenario characterizes the major cities on all continents, and corroborates with urban violence, poverty, environmental impacts and social exclusion. However, the lack of housing cannot be understood only as a quantitative aspect.

In this context, Brazil has developed initiatives such as the National Housing Plan (PlanHab) and the “My House, My Life” program (PMHML), designed to eliminate the housing shortage by 2022 (MINISTRY OF CITIES, 2010). As a result, the financial support of the Federal Government in recent years has fuelled the segment of social housing design (SHD), with a great participation in the growth of the construction industry.

Considering the large stock of these developments that is forming in the country, the efficient design and implementation of these projects is of utmost importance with regard to optimizing the use of resources. Based on the 3BL concept –(people, planet, profit), we should aim at the best cost-benefit ratio, from the point of view of the government, which acts as an investor, but also from a social and environmental perspective, given the importance of housing in people's lives.

In order to minimize environmental impacts, and corroborate the reduction of construction costs of SHD without neglecting the questions of habitability, it becomes essential to know the relationship between the decisions taken at the design stage and their influence on the final result. The choices made at this stage have the power to define and influence the environmental impacts, the final amount to be spent and the quality of a building. The management decisions have the ability to qualify such characteristics through volumetric solutions differentiated from those commonly found in the Brazilian market (AFONSO et al., 2011).

In Brazil, most SHD approved in the county are very similar to one another. They are generally composed of blocks of apartment buildings with five floors each and four two-bedroom units per floor. The articulation of the blocks with the circulation (routing and staircase) originates an H-shaped plan (Figure 1), which is ubiquitous in such projects. As Siqueira (2008) notes, this type of solution can be regarded as a reflection of the paradigm of economics in circulations, because they are not marketed by real estate. According to this author, due to a lack of theoretical background about the costs of decisions made in the design stage, architects and engineers end up simply adopting those solutions most commonly found in the market. As a consequence, there is a repetition of similar type buildings, which ignores features of the site where it will be deployed.

Figure 1: H-shaped SHD (http://www.suacidade.com/sites/default/files/images/minha_casa_minha_vida_2.jpg)

This paper discusses the H-shaped building design, largely used in SHD buildings, and aims to analyze environmental impacts, the cost and aspects of habitability of housing units in SHD, from a perspective based on the 3BL concept.

2. Triple Bottom Line concept (3BL)

In general, concern about the qualitative aspects of housing developments denotes not only a fundamental aspect of the quality of life of its residents, but also refers to the concept of social sustainability. Together with the economic and environmental dimensions, that forms the tripod of sustainable development known as Triple Bottom Line (3BL) - planet, people, profit (Silva, 2007). As defined by the WCED (1987), we should be able to meet the needs of the present, but ensuring that future generations can also meet their needs.

2.1 Environmental aspects (Planet)

By producing large physical assets, the construction industry consumes a large part of natural resources and energy produced worldwide. And, in addition, there is the enormous amount of waste generated, reaching about a third of the total volume generated by society as a whole (DEGANI and CARDOSO, 2002).

The outlook of the growth of the construction industry is part of a scenario associated with urban overcrowding, shortage of building materials and environmental impacts. According to Tavares (2006), as a consequence, there has been increased interest in the research and development of alternatives for housing and several studies on energy efficiency and consumption. Briefly, the environmental impacts associated with buildings can be divided into: (a) emissions of greenhouse gases, especially in the production of materials, (b) energy consumption in buildings, from the production of materials to its deconstruction; (c) consumption of natural resources, and (d) indirect impacts such as transportation (TAVARES, 2006).

Among the sectors directly related to construction, the importance of the residential sector in terms of energy consumption is equivalent to the commercial and public sectors taken together, considering all energy sources (BRAZIL, 2005). Roaf (2009) highlights that all construction materials have an impact on the environment, but it is much harder to accurately assess the total impact of a building. However, embodied energy (EE) may be seen as one of the most important parameters to assess environmental impact, since the use of non-renewable resources directly contributes to the degradation of the environment. According to Gauzin-Müller (2002), EE is the amount of energy consumed for the production of a product, from raw materials extraction to their distribution in the market.

The optimization of processes in the construction industry, especially targeting productivity gains, are being combined with studies and practices in order to reduce waste and minimize environmental impacts (WOLF et al., 2010). Soon, as the same authors state, the issue of sustainability will be incorporated into the processes related to construction. The sector is responsible for significant impacts to the environment, but it is currently seeking to improve its performance and reduce such damage.

2.2 Social aspects (People)

Historically, good examples of SHD are rare in Brazil, given the large number of projects already built or under construction that do not take into account adequate criteria for the habitability of units. Such projects are generally supported by the argument of cost limitation and by a legislation that establishes inferior requirements for the SHD segment, when compared to those established for residential projects outside this segment. As a result, the lack of adequate parameters for SHD, supported by legislation, is a reality in most buildings and minimizes basic requirements of comfort for its users. Lima et al (2011) observe that housing production in Brazil, especially in terms of SHD, has been highly criticized, due to excessive reduction of the areas and using materials of low quality. According to Villa (2009), the architectural quality of these projects is low, although this issue is of fundamental importance since it directly affects the daily lives and livelihood of the residents.

Among the precepts of habitability, passive solutions should be considered in order to meet the requirements of thermal comfort of users and avoid high maintenance costs over the life of the buildings. Thus, most of the solutions should be viable at the stage of design, such as the condition of cross ventilation in the environment and proper solar orientation, as exemplified by Olgyay (1998). Thus, the quality of life within the living space becomes a consequence of compliance with environmental standards of comfort, promoting a space that responds to the quality and function of healthy housing, responding to the concept of housing habitability (Bonduki, 2002).

Therefore, there is complex web of cultural values, ethical, human attitudes and behavior, in addition to environmental aspects, that must be taken into account in the formulation of strategies for efficient solutions, including interests and quality of life for people and local communities (SADAN; CHURCHMAN, 1996 apud SILVA, 2007).

2.3 Economic aspects (Profit)

The idea of reducing costs through the reduction of area is strongly rooted in the construction sector, and the parameter most widely used in Brazil to estimate costs is the BUC (basic unit cost) indicator, which expresses the unit cost per square meter for a standard project, considering several basic inputs (ABNT, 2006). However, the relationship between design decisions and the total cost of the building must also be considered. Rather than simply expressing the BUC, different studies as Otero et al. (2004), Guerra et al. (2009) and Mascaró (2010) show that there isn't a direct proportionality between built area and cost. That is, reductions in the area of a building do not necessarily imply a proportional reduction in production costs.

Mascaró (2010) relates the financial cost of a building directly to its form, through the so called Economic Index of Compactness (EIC). This parameter is expressed as the ratio between the perimeter of a circle of equal area and the perimeter of the outer walls in the building plan, incorporating edges and curves, since these imply increased production costs. Thus, the higher the EIC, the lower the construction costs, as well as construction waste generation. A higher EIC also tends to reduce costs during use and maintenance of the building (MASCARÓ, 2010).

The EIC is calculated by the formula: $EIC = (2\sqrt{(Sf\ x\ \pi)})/EP\ x\ 100$, where: "Sf" is the surface floor of the building and "EP" is the economic perimeter of the design, calculated by $EP = P + E/2$, where "P" is the real perimeter of the building and "E" is the number of edges. In addition, Mascaró (2010) indicates that the horizontal planes represent approximately 25% of the total cost of a project, the vertical planes 45%, electrical and hydraulic installations 25%, and facilities at construction site about 5%. The vertical planes (envelope) offer numerous alternatives for both the design and for the use of materials, and it can be varied both in quantity and in quality. Thus, when economic factors are essential, the most logical thing to save money is to optimize these surfaces, rather than simply reducing the plan areas of housing units (MASCARÓ, 2010).

3. Methodology

The architectural design of a SHD currently under construction in the south of Brazil has been selected for the case study. The apartment buildings in this project have the H-shaped design that is predominant in Brazil for this type of construction. The blocks were designed in structural masonry, and they are referred here as the base-design study (Figure 2).

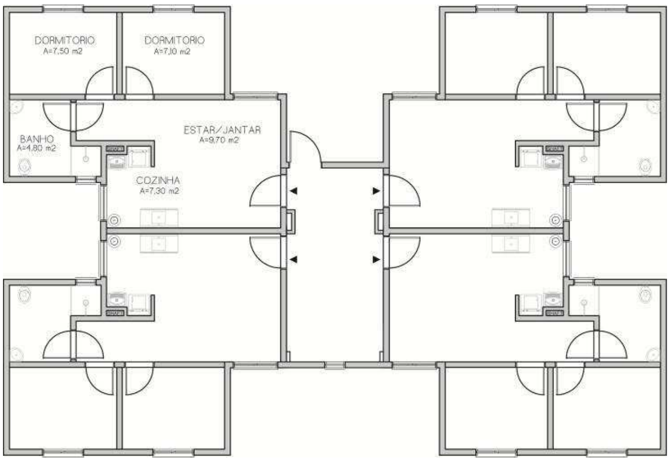

Figure 2: H-shaped base-design, commonly used in SHD in Brazil

Taking the base-design as a reference, changes were made in the building volumetry, seeking alternatives with higher EIC and lower consumption of materials, but always keeping the same total floor plan area (204 m²). Based on the literature, the plant design we seek to achieve is rectangular, having the least number of edges, with the lower length / width ratio as possible in order to improve EIC, as proposed by Mascaró (2010).

After, the consumption of materials of the base-design and proposed designs were quantified using the Revit software with BIM (Building Information Modeling) technology. As a result, alternatives to the base-design were analyzed for total cost and habitability aspects (cross ventilation, better natural lighting and plant flexibility).

The environmental impacts were analyzed comparing the EE of the base-design to the alternative designs with improved EIC, called the proposed designs. The materials budgeting required for construction are listed in Table 2. As the main goal of this research is not to get the absolute EE consumed in each project, but rather to compare the environmental impacts caused by each of the alternatives, some elements were considered as similar for both systems. However, instead of excluding them from the calculation, these values were calculated based on the base-design and replicated in the proposed design.

This study also analyzed the stages of production and transportation of materials and their application in the construction of the building. The stages of operation, maintenance and demolition were not counted because they would be similar for both proposals. From the quantification of the materials, as described in table 2, the total EE values were calculated based on Tavares (2006) research, which provided EE data (in MJ/kg) for materials produced locally.

The item Masonry includes, besides the ceramic blocks, mortar blocks and tiles, roughcast, and plaster. Finally, we included energy from transportation for an average distance of 80 km (TAVARES, 2006).

4. Results and discussion

Figures 3 and 4 show the changes made to the base-design, maintaining the same surface area of the floor plan (204 m²) and the housing unit area of about 39 m².

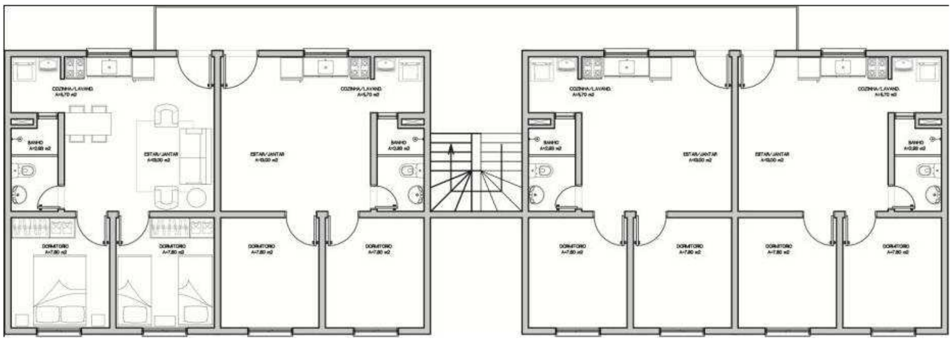

Figure 3: Proposed design A, with open lateral hall and central staircase

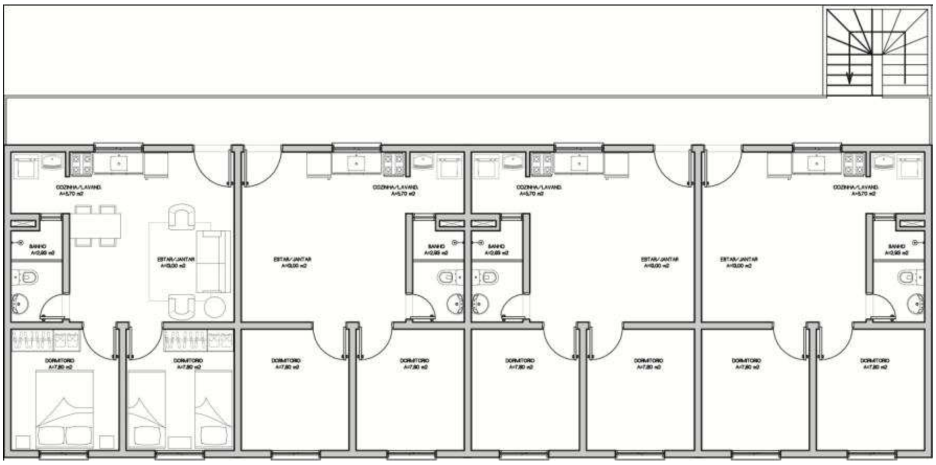

Figure 4: Proposed design B, bar-shaped with open lateral hall

Summarizing the results, Table 1 shows the morphological changes proposed, the design configuration and the EIC obtained for the alternatives developed.

Table 1: Base-design and proposed designs A and B, with their EIC

Typology	Configuration	Total area	EIC
Base-design (Figure 1)	H-shaped design with a vertical circulation serving 04 apartments per floor	204 m^2 x 5 = 1020 m²	49,6
Proposed design A (Figure 2)	Bar design with a vertical circulation, parcial lateral hall serving 04 apartments per floor	204 m^2 x 5 = 1020 m²	63,2
Proposed design B (Figure 3)	Bar design with a vertical circulation, total lateral hall serving 04 apartments per floor	204 m^2 x 5 = 1020 m²	72,3

As described in the methodology, after obtaining the EIC of the designs, the analysis of environmental impact was done through the calculation of EE in the base-design and proposed design with the best EIC (in this case, the proposed design B of figure 3). The material budgeting for each building part, as well as the quantification of EE for the two alternatives, are summarized in Table 2.

Table 2: Material budgeting and quantification of EE for each building

		Base-design			Proposed design B		
Building composition	EI (MJ/kg)	Amount	Total (kg)	Total (MJ)	Amount	Total (kg)	Total (MJ)
1. Preliminary services: lease of the work, siding, temporary shelter		-	-	17567	-	-	17567
2. Structure							
2.1. Infrastructure							
Wood 15mm (5x)	0,5	1,8 m³	1080	540	1,8 m³	1080	540
Steel - armor	31	-	1080	33480	-	1080	33480
Waterproofing (3x)	96	-	30	2880	-	30	2880
Medium sand	0,05	6,83 m³	10350	517,5	6,83 m³	10350	517,5
Crushed stone	0,15	8,36 m³	13800	2070	8,36 m³	13800	2070
Portland cement CP II-E32	4,2	1,77 m³	3450	14490	1,77 m³	3450	14490
2.2. Superstructure							
Offset wooden plate 12mm (3x)	8	14,4 m³	10397	83175	13,5 m³	9706	77645

Wooden struts d=10cm	0,5	-	19908	9954	-	18900	9450
Steel nails 18x27	31	-	25	775	-	25	775
Steel - armor	96	-	10833	1039910	-	10116	971136
Medium sand	0,05	68,5 m³	103810	5191	63,9 m³	96945	4847
Crushed stone	0,15	83,9 m³	138414	20762	78,3 m³	129260	19389
Portland cement CP II-E32	4,2	17,7 m³	34603	145335	16,6 m³	32315	135723
2.3. Concrete stairs							
Medium sand	0,05	2,84 m³	4312,5	215,62	2,84 m³	4312,5	215,62
Crushed stone	0,15	3,48 m³	5750	862,5	3,48 m³	5750	862,5
Portland cement CP II-E32	4,2	0,73 m³	1437,5	6037,5	0,73 m³	1437,5	6037,5
Steel - armor	31	-	500	15500	-	500	15500
Steel - railing	31	-	29276	780704	-	29276	780704
3. Masonry							
Ceramic block 14x19x29	2,9	235 m³	329000	954100	187 m³	261800	759220
Solid brick 6x11x22	2,9	6,31 m³	8828	25602	7,34 m³	10276	29800
Medium sand	0,05	42,3 m³	64344	2893,1	30,6 m³	46344	2317,2
Hydrated lime CH III	3	9,07 m³	13609	40829	6,75 m³	10113,4	30339,8
Portland cement CP II-E32	4,2	4,77 m³	9292	39028,5	3,34 m³	6535,5	27451,2
White cement (non-structural)	4,2	0,245 m³	478	2006,5	0,18 m³	351	1474,2
Tiles	6,2	490 m²	5880	36456	360 m²	4320	26784
4. Frames							
Wooden door (complete)	3,5	-	6645	23257,6	-	6645	23257,6
Steel nails, screws and hinges	37	-	184,6	6774	-	184,6	6774
Brass – door lock	55	-	710,8	39094	-	710,8	39094
Aluminum – frame and profiles	98	-	9837,5	964075	-	9837,5	964075
Glass	18	-	5675,4	102157	-	5675,4	102157
5. Roof							
Wood – peroba (structure)	0,5	2,44 m³	1756,8	878,4	2,35 m³	1692	846
Steel nails 18x27	31	-	16	496	-	15,5	480,5
Fiber cement tiles-8mm (i=27%)	6	2,05 m³	3935,2	23611,4	2,0 m³	3840	23040
Fiber cemente ridge	6	0,045 m³	85,68	514,07	0,04 m³	76,8	460,8
Gutter - galvanized	33,8	0,185 m³	1450,8	49038,3	0,15 m³	1177,5	39799,5
Canvas (PEAD)	95	200 m²	190	18050	200 m²	190	18050
Bathroom waterproofing	96	-	12	1152	-	10	960
PVC liner (bathrooms)	80	96,4 m²	1253,2	100256	50,0 m²	650	52000
6. Floors							
Tile	5	1212 m²	25246	126230	1290m²	26870,7	134353
Medium sand	0,05	27,56 m³	41756	2087,8	29,7 m³	45071	2253,5
Hydrated lime CH III	3	8,37 m³	12552	37657,4	9,04 m³	13569,5	40708,6
Portland cement CP II-E32	4,2	1,05 m³	2049,4	8607,4	1,12 m³	2181,2	9161,3
7. Installations							
7.1. Hydraulic installations							
Fiberglass tank	24	-	600	14400	-	600	14400
Hydraulic system (PVC)	80	-	546,2	43696	-	546,2	43696
Sanitary ware	25	-	600	15000	-	600	15000
7.2. Electric installations							
Breakers, conduit, eletr wiring, switches		-	-	188245	-	-	188245
8. Painting							
8.1. Interior walls and ceilings painting							
Acrylic sealer	61	2560 m²	399,36	24360,9	2316m²	361,29	22039
Latex PVA paint (2 coating)	65	5256 m²	819,94	53295,8	4736m²	738,81	48023
8.2. External walls painting							
Acrylic sealer	61	83,82 m²	13,075	797,63	75,0 m²	11,7	713,7
Acrylic paint (2 coating)	61	2190 m²	341,64	20840	1278m²	199,36	12161,4
8.3. Frames painting							

Enamel paint	98	486 m²	120	11760	486 m²	120	11760
9. Final works (cleaning)	1	1200			1200		
Transport EE (MJ)	0,13	121846,9			107854,2		
Overall EE (MJ)		5.280.259,82			4.893.778,62		

4.1 Analysis of environmental aspects (Planet)

The difference between the EE of the base-design and the proposed design is about 386481,2 MJ, which represents a reduction of 7.5% in favor of the bar-shaped alternative. This result can be explained by the decrease of material consumption between projects, especially in masonry and painting materials (by decreasing the outer perimeter).

Converting the difference of EE in electric power, we obtain 107,355.94 kWh. Assuming an average consumption of 100 kWh/month (current limit of the intermediate discount bracket of social power rate, as described in BRAZIL, 2010), we have that the savings would be enough to meet the total energy needs of a single unit for almost 90 years, or 20 units (a tower) for approximately 4.5 years. Figures 4 and 5 illustrate the variation of embodied energy (EE) in the buildings as a function of the compactness index (EIC) for each design alternative.

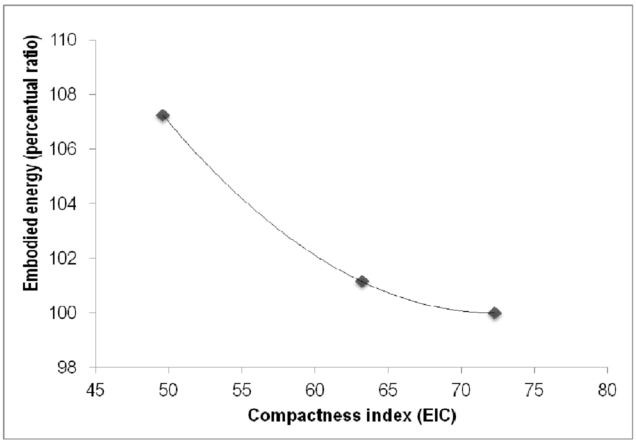

Figure 4: Building embodied energy (percentual ratio) versus compactness index

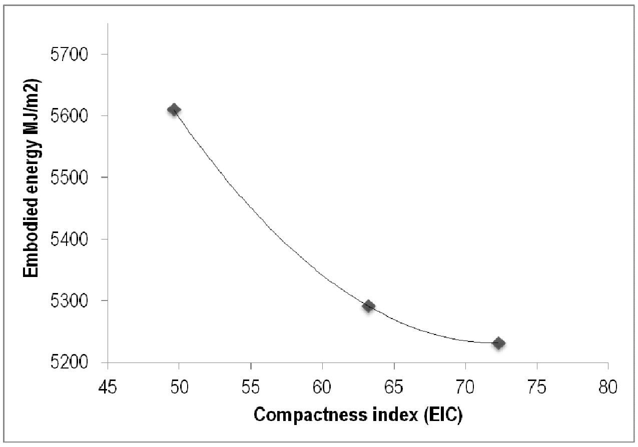

Figure 5: Building embodied energy (MJ/m²) versus compactness index

The first graph shows the relation between the EE and the EIC in a percentual ratio; the second one presents the absolute values of EE in MJ/m². Summarizing, the higher the EIC is, less material is consumed and thereby less environmental impact. It should be emphasized that this condition has been reached only with design changes and morphology optimization, with no changes to floor plan area.

4.2 Analysis of social aspects (People)

Fundamental to the health of individuals, proper illumination and thermal comfort are privileged in the proposed designs, since all housing units are facing the same solar orientation. When feasible due to the implementation on the ground, you can have all dormitories facing better sunlight, which is impossible in H-shaped designs.

This configuration also allows natural cross ventilation, which can provide greater thermal comfort, especially in hot and humid climates. It may also improve energy efficiency in indoor environments, reducing energy consumption, minimizing directly the use of mechanical ventilation systems and air conditioning. In addition, natural ventilation minimizes outbreaks of mold and mildew on the furniture and even walls.

These issues are not answered in the base-design, due to its H-shape. The base-design apartments do not have cross ventilation and one side will always be less exposed to sunlight, which impairs natural lighting and ventilation.

4.3 Analysis of economic aspects (Profit)

Taking as a parameter the economic index of compactness (EIC), there is a cost reduction in the two proposed designs. While the base-design features an EIC of 49.6, the proposed design have an EIC around of 63.2 and 72.3, respectively.

This difference is explained by the decrease of the external perimeter and decreasing edge, directly related to the vertical planes, items of greater direct contribution to the cost of a building. Using the curve relating cost and compactness index (developed by MASCARÓ, 2010) the difference between EICs 50 and 70 corresponds to a reduction of production cost of approximately 10%. This savings can be reversed into improvements such as increased area, larger frames, best quality finishing, among others.

5. Conclusion

The results obtained illustrate important guidelines that can be followed during the phases of conception and design of social housing units. The differences found in the EIC from the base-design in relation to proposed designs indicate that significant savings can be made from volumetric decisions in the early stages of a design.

The savings achieved during the production process can be reversed into benefits and improvements to SHD in order to qualify not only the housing units, but also directly influence the way of life of its users.

In addition, the reduction in EE between the base-design and the proposed design (of about 7.5%) points to a considerable reduction in the environmental impact through the decrease of energy consumption in the production of these buildings.

Based on these results, we question the serial reproduction of typologies commonly found in the SHD segment, without a careful evaluation of the decisions that affect the cost, quality and the impacts of these developments.

Finally, we believe 3BL sustainability aspects such as the ones described here should be extensively discussed by the government and society, and common-sense indexes such as the EIC could be incorporated early into the SHD process in order to cut production costs, reduce environmental impact and improve quality and living conditions.

Architecture has the ability to transform and contribute directly to the improvement of people's lives. More than a quantitative problem, eliminating the housing shortage and providing universal access to basic services should be seen as a serious sustainability challenge that can be better addressed when the 3BL concept is put into practice.

References

AFONSO, S; OLIVEIRA, R de; LOGSDON, L (2011) A funcionalidade e a flexibilidade como garantia de qualidade do projeto de habitação de interesse social. *In: SIMPÓSIO BRASILEIRO DE QUALIDADE DO PROJETO NO AMBIENTE CONSTRUÍDO*, 10., 2011, Rio de Janeiro: Anais... Rio de Janeiro: UFRJ.

ASSUMPÇÃO, J F P (2003) Análise de investimentos na construção civil. In: *III Simpósio Brasileiro de Gestão e Economia da Construção*. ANTAC: São Carlos, setembro de 2003. Apostila de curso.

BONDUKI, N G (2004) *Origens da habitação social no Brasil:* Arquitetura Moderna, Lei do Inquilinato e Difusão da Casa Própria. São Paulo: Estação Liberdade.

BRAZIL (2005) Ministério de Minas e Energia, Empresa de Pesquisa Energética. *Balanço Energético Nacional 2005*: Ano base 2004. Brasília.

BRAZIL. Lei n. 12.212, de 20 de janeiro de 2010, que dispõe sobre a Tarifa Social de Energia Elétrica. Brasília, Câmara dos Deputados, Coordenação de Publicações, 2010.

DEGANI, C M; CARDOSO, F F (2003) Aplicabilidade de sistemas de gestão ambiental em empresas construtoras de edifícios. *Ambiente Construído*, Porto Alegre, v. 3, n. 3, p. 33-43.

GAUZIN-MÜLLER, D (2002) *Arquitectura ecológica*. Barcelona: Gustavo Gili.

GUERRA, G M; KERN, A P; GONZÁLEZ, M A S (2009) Empreendimentos de habitação de interesse social: o desafio na relação área/custo. *Teoria e Prática na Engenharia Civil*, n. 14, p. 51-58.

HIROTA, E H (1987) Estudo exploratório sobre a tipificação de projetos de edificações, visando a reformulação da norma brasileira NB-140/65. Dissertação (Mestrado em Engenharia Civil), Programa de Pós-Graduação em Engenharia Civil, UFRGS, Porto Alegre.

LIMA, L P; FORMOSO, C T; ECHEVESTE, M E S (2011) Proposta de um protocolo para o processamento de requisitos de cliente em empreendimentos habitacionais de interesse social. *Ambiente Construído*, Porto Alegre, v. 11, n. 2, p. 21-37.

LOBO, F H R; SANTOS, A de P L; TAVARES, S F (2010) Ferramentas de planejamento para levantamento de inventário de emissão de CO_2: estudo de caso. *Revista IJIE*, Florianópolis, v. 2, n. 2, p. 26-43.

MASCARÓ, J L (2010) *O custo das decisões arquitetônicas*. 5. ed. Porto Alegre: Masquatro.

MINISTÉRIO DAS CIDADES (2011) *Plano Nacional de Habitação*. (available online http//:www.cidades.gov.br [acessed on 30/12/2011).

OLGYAY, V W (1998) Arquitectura y clima: manual de diseño bioclimático para arquitectos y urbanistas. Barcelona: Gustavo Gili.

ORNSTEIN, S W; ROMÉRO, M A (2003) *Avaliação Pós-Ocupação: métodos e técnicas aplicados à habitação social.* Coleção Habitare. Porto Alegre: ANTAC.

OTERO, J A; HEINECK, L F M (2004) Análise paramétrica para estimativa de custos na construção de edifícios. *In: Conferência Latino Americana de Construção Sustentável. Encontro Nacional de Tecnologia do Ambiente Construído, 10.* São Paulo. Anais... São Paulo: ANTAC.

ROAF, S (2009) *Ecohouse: a casa ambientalmente sustentável*. 3.ed. Porto Alegre: Bookman.

TAVARES, S F (2006) *Metodologia de análise do ciclo de vida energético de edificações residenciais brasileiras.* Tese (Doutorado em Engenharia Civil), Curso de Pós-graduação em Engenharia Civil, UFSC, Florianópolis.